US012154711B2

(12) **United States Patent**
Takeda et al.

(10) **Patent No.: US 12,154,711 B2**
(45) **Date of Patent: Nov. 26, 2024**

(54) **ADHESIVELY-LAMINATED CORE FOR STATOR AND ELECTRIC MOTOR**

(71) Applicant: **NIPPON STEEL CORPORATION**, Tokyo (JP)

(72) Inventors: **Kazutoshi Takeda**, Tokyo (JP); **Ryu Hirayama**, Tokyo (JP)

(73) Assignee: **NIPPON STEEL CORPORATION**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 697 days.

(21) Appl. No.: **17/294,519**

(22) PCT Filed: **Dec. 17, 2019**

(86) PCT No.: **PCT/JP2019/049266**
§ 371 (c)(1),
(2) Date: **May 17, 2021**

(87) PCT Pub. No.: **WO2020/129925**
PCT Pub. Date: **Jun. 25, 2020**

(65) **Prior Publication Data**

US 2022/0020521 A1 Jan. 20, 2022

(30) **Foreign Application Priority Data**

Dec. 17, 2018 (JP) 2018-235864

(51) **Int. Cl.**
H01F 27/245 (2006.01)
H01F 41/02 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H01F 27/245*** (2013.01); ***H01F 41/0233*** (2013.01); ***H02K 1/185*** (2013.01); ***H02K 15/024*** (2013.01)

(58) **Field of Classification Search**
CPC . C09J 133/04; C09J 2203/326; H01F 27/245; H01F 41/0233; H01K 1/04;
(Continued)

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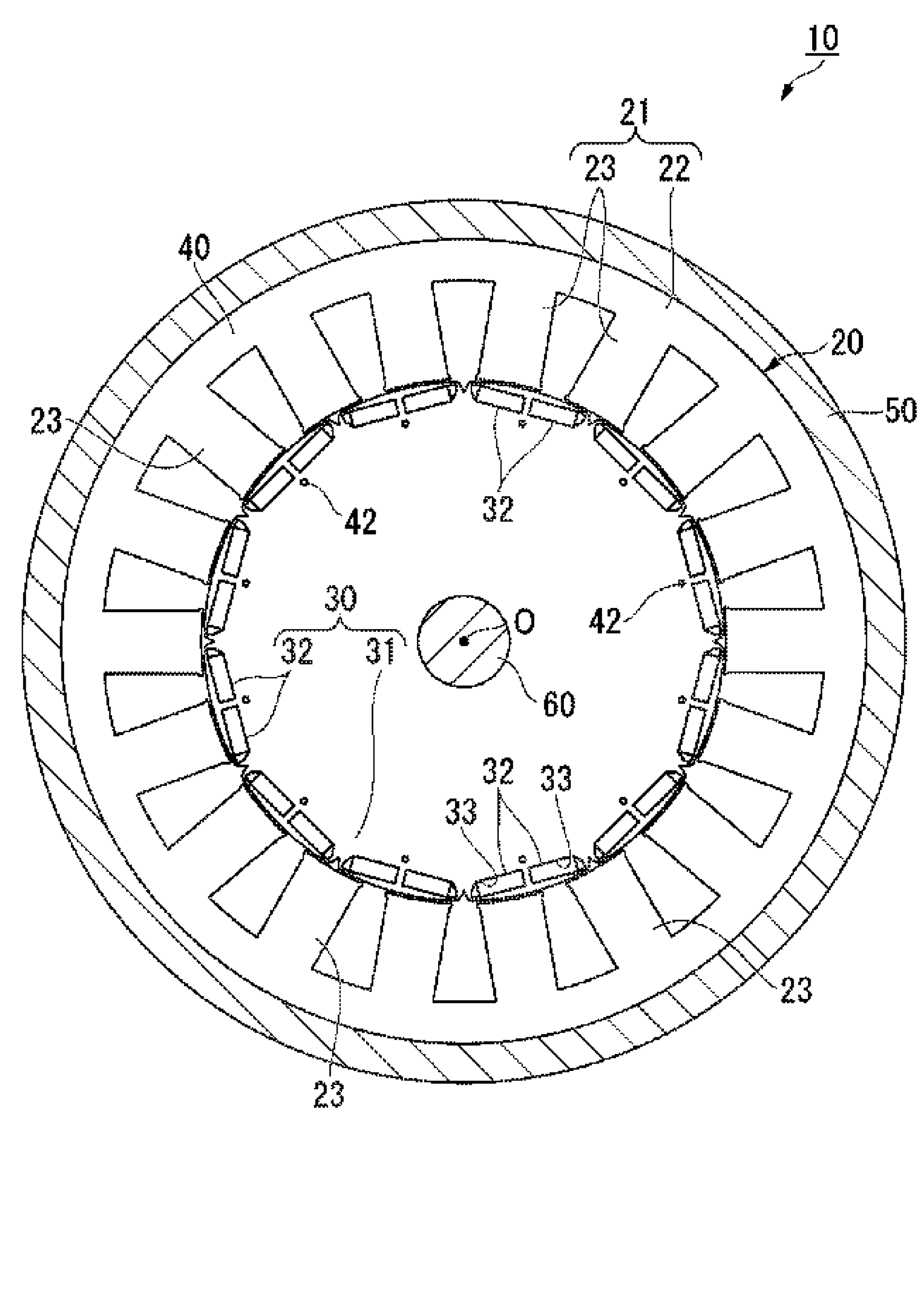
Primary Examiner — Kevin C T Li
(74) *Attorney, Agent, or Firm* — Renner, Otto, Boisselle & Sklar, LLP

(57) **ABSTRACT**

Provided is an adhesively-laminated core for a stator including: a plurality of electrical steel sheets which have phosphate-based insulation coatings on surfaces thereof and are overlapped coaxially with each other; and adhesion parts provided between the respective electrical steel sheets, an average thickness of the insulation coatings is 0.3 μm to 1.2 μm, an average thickness of the adhesion parts is 1.0 μm to 3.0 μm, and in a case where the average thickness of the insulation coating is defined as t1 in a unit of μm, and the average thickness of the adhesion parts is defined as t2 in a unit of μm, the following Equation 1 is satisfied.

$$-4.3\times t1+3.6\leq t2\leq -4.3\times t1+6.9 \quad \text{(Equation 1)}$$

6 Claims, 5 Drawing Sheets



(51) **Int. Cl.**
H02K 1/18 (2006.01)
H02K 15/02 (2006.01)

(58) **Field of Classification Search**
CPC H01K 1/18; H01K 1/185; H01K 15/02; H01K 15/024; H01K 2213/03; Y02T 10/64; H02K 1/185
See application file for complete search history.

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FIG. 1

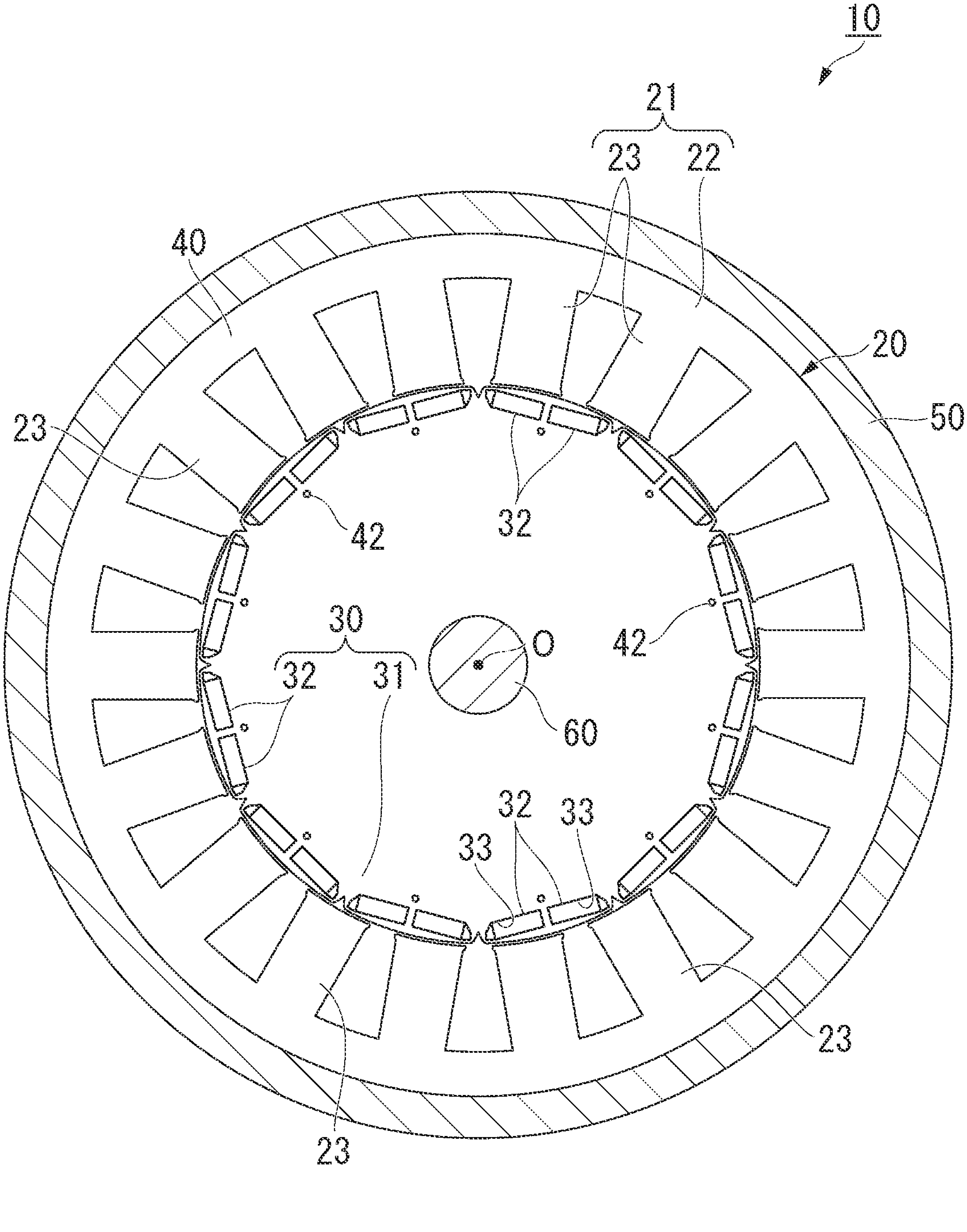


FIG. 2

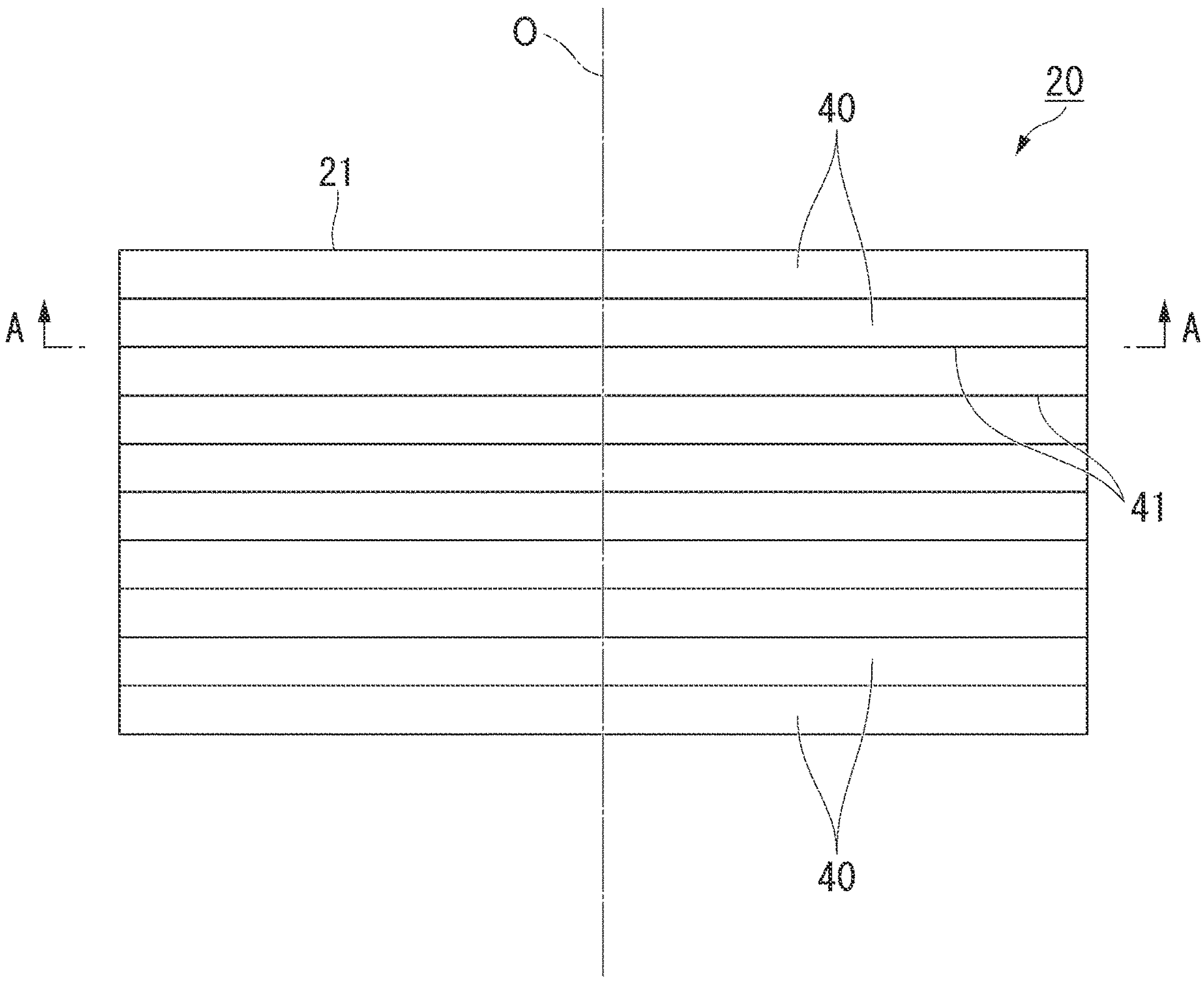


FIG. 3

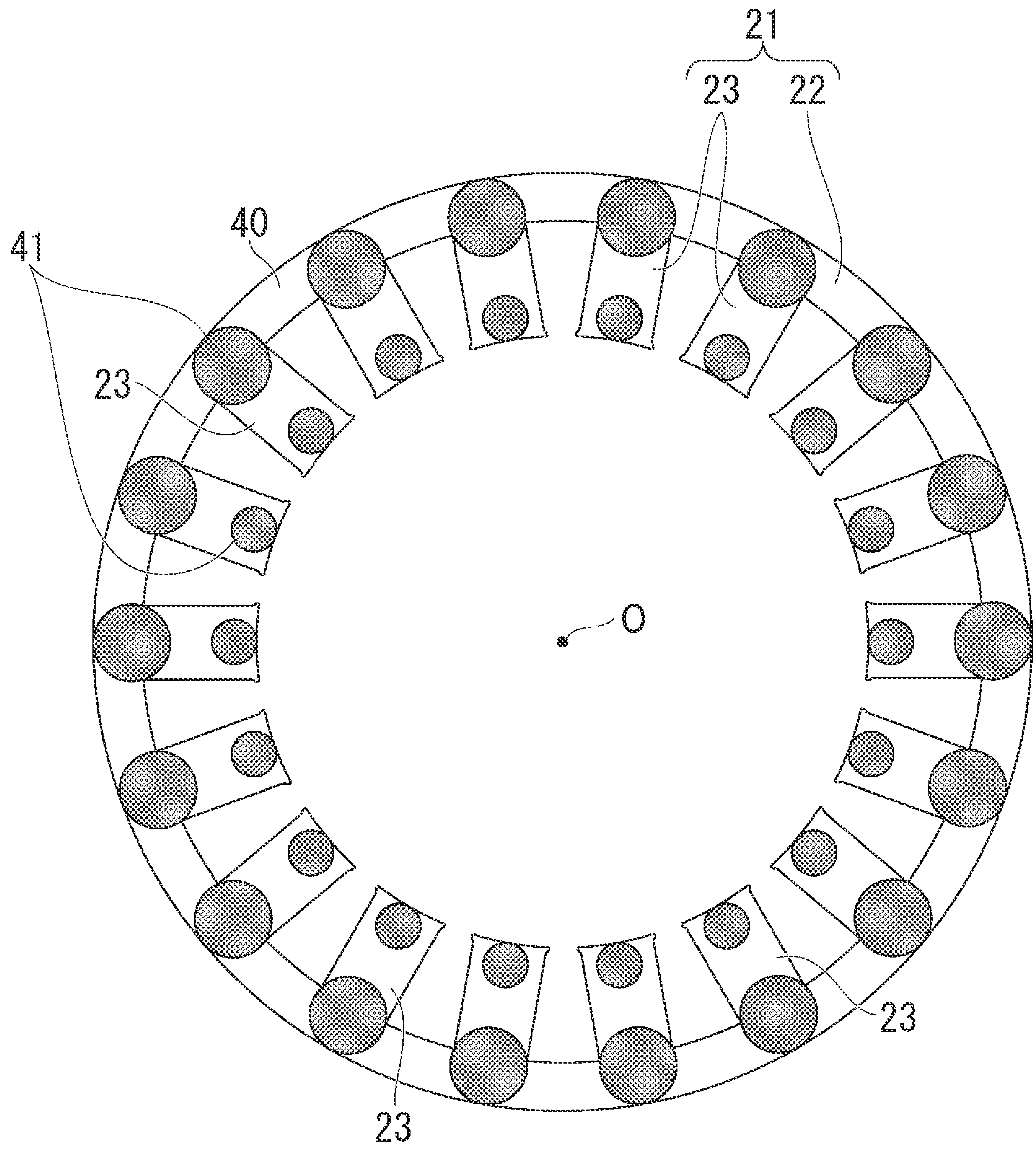
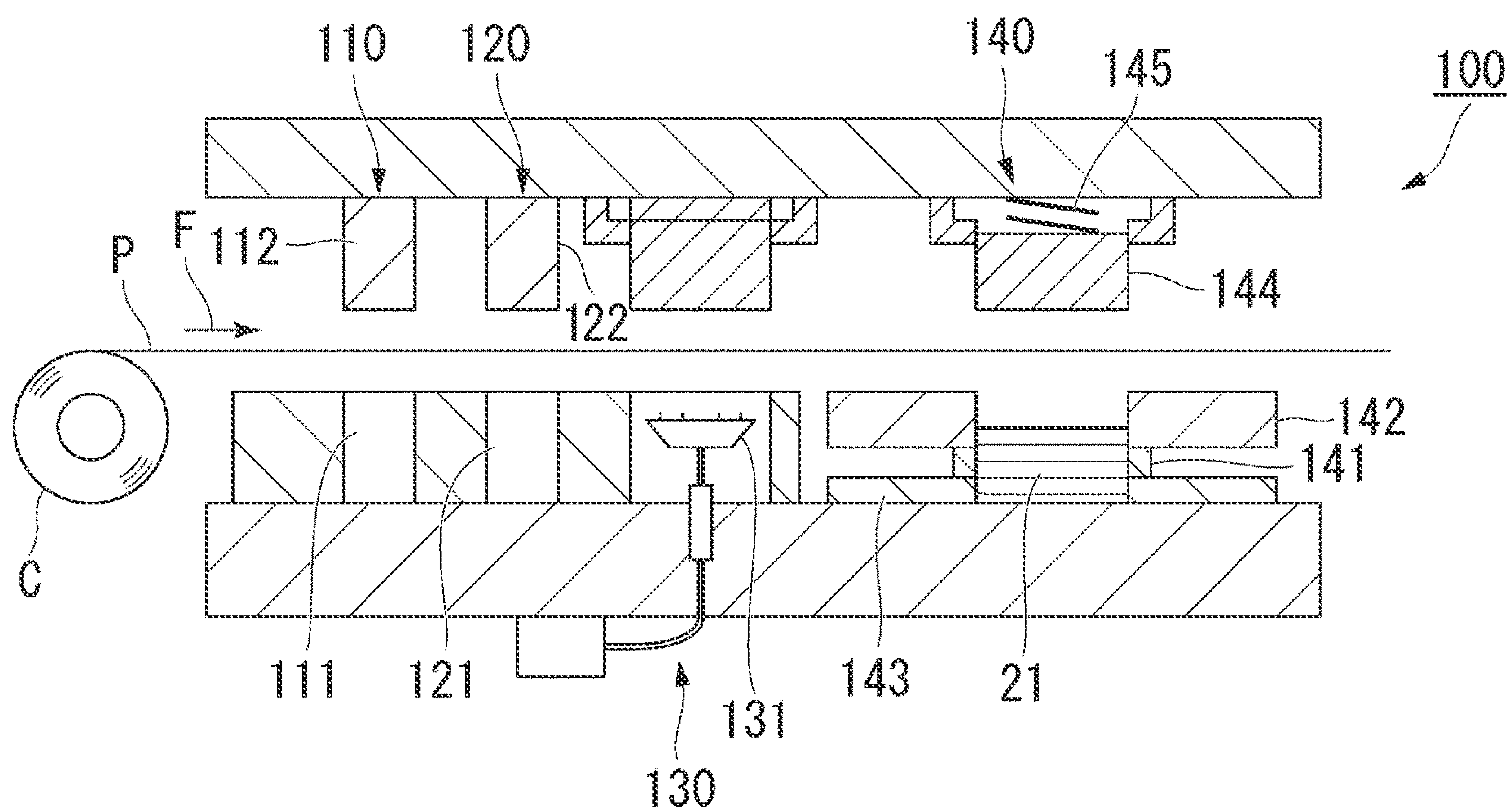


FIG. 4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120
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100
112
F
P
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142
141
C
111
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143
21
130

FIG. 5

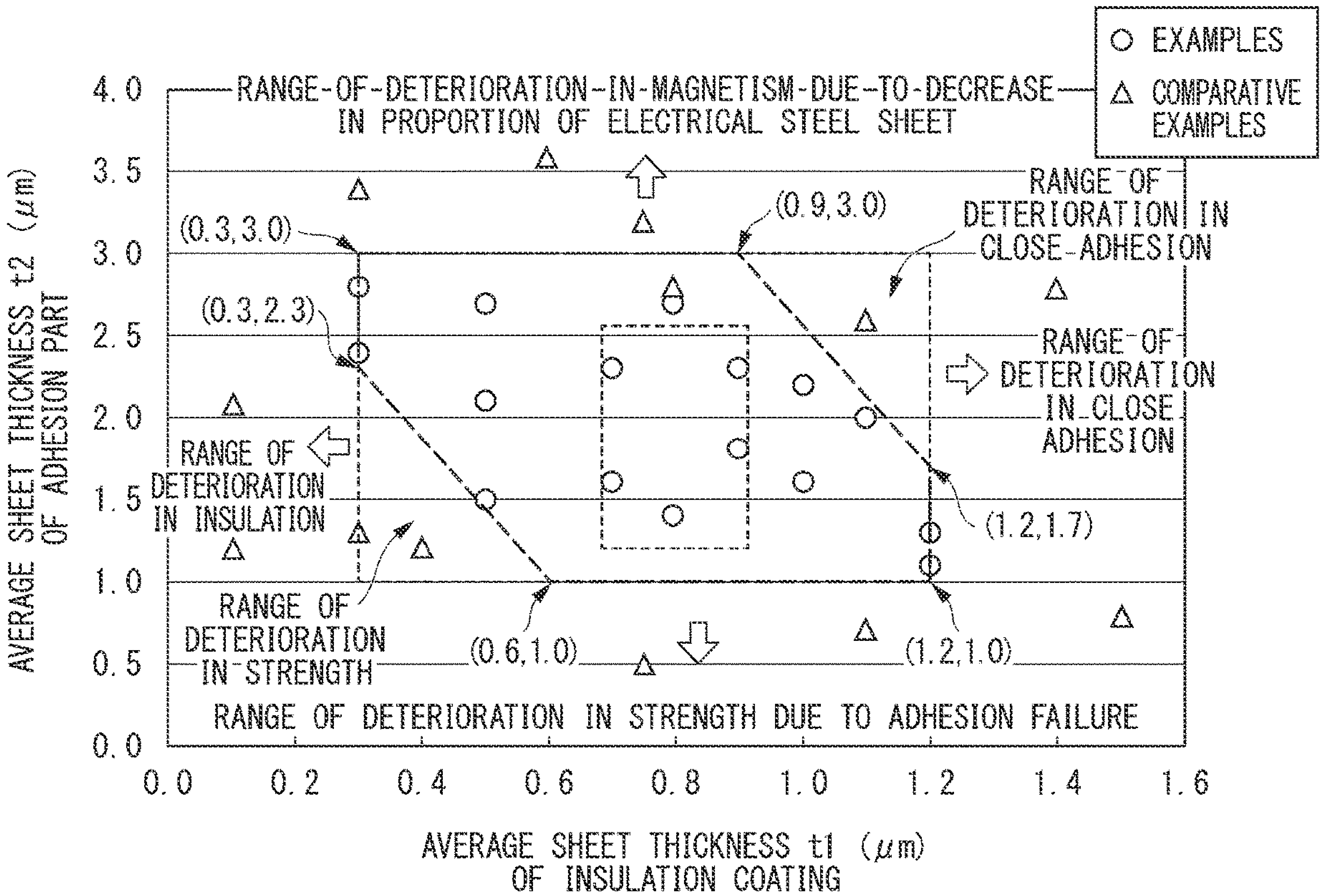
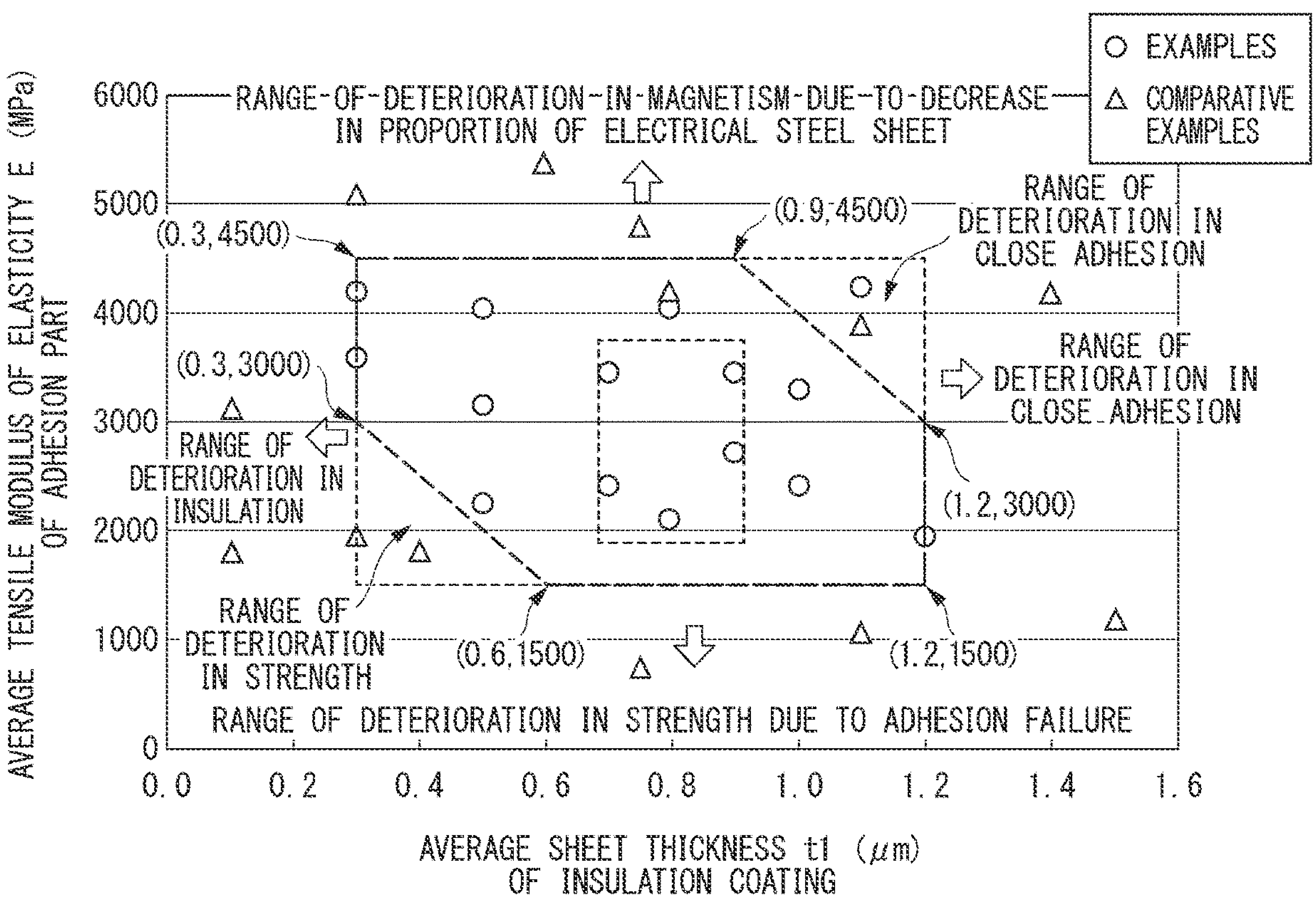

EXAMPLES
COMPARATIVE EXAMPLES
RANGE OF DETERIORATION IN MAGNETISM DUE TO DECREASE IN PROPORTION OF ELECTRICAL STEEL SHEET
RANGE OF DETERIORATION IN CLOSE-ADHESION
RANGE OF DETERIORATION IN CLOSE ADHESION
RANGE OF DETERIORATION IN INSULATION
RANGE OF DETERIORATION IN STRENGTH
RANGE OF DETERIORATION IN STRENGTH DUE TO ADHESION FAILURE
(0.3,3.0)
(0.9,3.0)
(0.3,2.3)
(1.2,1.7)
(0.6,1.0)
(1.2,1.0)
AVERAGE SHEET THICKNESS t2 (μm) OF ADHESION PART
AVERAGE SHEET THICKNESS t1 (μm) OF INSULATION COATING
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0.2
0.4
0.6
0.8
1.2
1.4
1.6

FIG. 6


EXAMPLES
COMPARATIVE EXAMPLES
RANGE OF DETERIORATION IN MAGNETISM DUE TO DECREASE IN PROPORTION OF ELECTRICAL STEEL SHEET
RANGE OF DETERIORATION IN CLOSE ADHESION
RANGE OF DETERIORATION IN INSULATION
RANGE OF DETERIORATION IN STRENGTH
RANGE OF DETERIORATION IN STRENGTH DUE TO ADHESION FAILURE
(0.3,4500)
(0.9,4500)
(0.3,3000)
(1.2,3000)
(0.6,1500)
(1.2,1500)
AVERAGE TENSILE MODULUS OF ELASTICITY E (MPa) OF ADHESION PART
AVERAGE SHEET THICKNESS t1 (μm) OF INSULATION COATING
6000
5000
4000
3000
2000
1000
0
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

ADHESIVELY-LAMINATED CORE FOR STATOR AND ELECTRIC MOTOR

TECHNICAL FIELD

The present invention relates to an adhesively-laminated core for a stator and an electric motor.

Priority is claimed on Japanese Patent Application No. 2018-235864, filed Dec. 17, 2018, the content of which is incorporated herein by reference.

BACKGROUND ART

Conventionally, a laminated core as described in Patent Document 1 below is known. Patent Document 1 below discloses a direct drive motor including a stator disposed coaxially with and inside the rotor. In addition, an insulation coating and an adhesion coating are formed on an electrical steel sheet on a stator side. It is described that when the insulating coating is thinner than 0.80 μm, a sufficient dielectric strength cannot be obtained, and when it is thicker than 1.20 μm, an excitation efficiency is not good. On the other hand, it is described that when the adhesion coating is thinner than 1.80 μm, a sufficient adhesion ability cannot be obtained, and when it is thicker than 2.20 μm, an excitation efficiency is not good.

CITATION LIST

Patent Document

Patent Document 1

Japanese Unexamined Patent Application, First Publication No. 2015-12756

SUMMARY OF THE INVENTION

Problems to be Solved by the Invention

When an adhesive is applied thinly to make an adhesion part thinner, a proportion of electrical steel sheets in a laminated core increases. However, as described in Patent Document 1, when the adhesion part is too thin, the adhesion strength decreases. Therefore, it is conceivable to form a soft adhesion part using a soft adhesive while ensuring the adhesion strength. However, in this case, stress concentration occurs in the insulation coating due to a force applied when the adhesive cures and shrinks, and thus the electrical steel sheet easily peels off. The technique disclosed in Patent Document 1 does not recognize such a problem and, as a matter of course, cannot solve it.

The present invention has been made in view of the above circumstances, and an object thereof is to provide an adhesively-laminated core for a stator that can both prevent peeling of an insulation coating and inhibit deterioration of magnetic properties due to a stress applied to an electrical steel sheet by an adhesion part, and an electric motor including the adhesively-laminated core for a stator.

Means for Solving the Problem

In order to solve the above problem, the present invention employs the following means.

(1) One aspect of the present invention is an adhesively-laminated core for a stator including: a plurality of electrical steel sheets which have phosphate-based insulation coatings

on surfaces thereof and are overlapped coaxially with each other; and adhesion parts provided between the respective electrical steel sheets, in which, an average thickness of the insulation coatings is 0.3 μm to 1.2 μm, an average thickness of the adhesion parts is 1.0 μm to 3.0 μm, and in a case where the average thickness of the insulation coating is defined as t1 in units of μm, and the average thickness of the adhesion parts is defined as t2 in a unit of μm, the following Equation 1 is satisfied.

$$-4.3\times t1+3.6\leq t2\leq -4.3\times t1+6.9 \quad \text{(Equation 1)}$$

(2) In the aspect according to the above (1), the following configuration may be adopted: the average thickness t1 is 0.7 μm to 0.9 μm; and the average thickness t2 is 1.2 μm to 2.6 μm.

(3) In the aspect according to the above (1) or the above (2), the following configuration may be adopted: an average tensile modulus of elasticity E of the adhesion parts is 1500 MPa to 4500 MPa; and the average tensile modulus of elasticity E (MPa) and the average thickness t1 (μm) of the insulation coating satisfy the following Equation 2.

$$-5000\times t1+4500\leq E\leq -5000\times t1+9000 \quad \text{(Equation 2)}$$

(4) In the aspect according to the above (3), the following configuration may be adopted: the average tensile modulus of elasticity E is 1800 MPa to 3650 MPa; and the average thickness t1 is 0.7 μm to 0.9 μm.

(5) In the aspect according to any one of the above (1) to (4), the adhesion parts may be room temperature curing type acrylic-based adhesives each containing SGA made of an elastomer-containing acrylic-based adhesive.

(6) In the aspect according to any one of the above (1) to (5), an average sheet thickness of the electrical steel sheets may be 0.15 mm to 0.35 mm.

(7) An electric motor according to one aspect of the present invention includes the adhesively-laminated core for the stator according to any one of the above (1) to (6).

Effects of the Invention

According to each aspect of the present invention, an adhesively-laminated core for a stator that can both prevent peeling of an insulation coating and inhibit deterioration of magnetic properties due to a stress applied to an electrical steel sheet by an adhesion part, and an electric motor including the adhesively-laminated core for the stator can be provided.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a cross-sectional view of an electric motor including an adhesively-laminated core for a stator according to one embodiment of the present invention.

FIG. **2** is a side view of the laminated core for the stator.

FIG. **3** is a cross-sectional view along line A-A in FIG. **2**, showing an example of a formation pattern of adhesion parts in the adhesively-laminated core for the stator.

FIG. **4** is a side view of a manufacturing device used for manufacturing an example of the adhesively-laminated core for the stator.

FIG. **5** is a graph showing a relationship between an average thickness t1 of an insulation coating and an average thickness t2 of the adhesion parts in the same example.

FIG. **6** is a graph showing a relationship between the average thickness t1 of the insulation coating and an average tensile modulus of elasticity E of the adhesion parts in the same example.

EMBODIMENTS FOR IMPLEMENTING THE INVENTION

Hereinafter, with reference to the drawings, an adhesively-laminated core for a stator and an electric motor including the adhesively-laminated core for the stator according to one embodiment of the present invention will be described. Also, in the present embodiment, as the electric motor, a motor, specifically, an AC motor, more specifically, a synchronous motor, and more specifically, a permanent magnetic electric motor will be described as an example. This type of motor is suitably adopted for, for example, an electric vehicle.

As shown in FIG. **1**, an electric motor **10** includes a stator **20**, a rotor **30**, a case **50**, and a rotation shaft **60**. The stator **20** and the rotor **30** are accommodated in the case **50**. The stator **20** is fixed to the case **50**.

In the present embodiment, as the electric motor **10**, an inner rotor type electric motor in which the rotor **30** is located inside the stator **20** in a radial direction thereof is adopted. However, as the electric motor **10**, an outer rotor type electric motor in which the rotor **30** is located outside the stator **20** may be adopted. Further, in the present embodiment, the electric motor **10** is a three-phase AC motor having 12 poles and 18 slots. However, the number of poles, the number of slots, the number of phases, and the like can be changed as appropriate.

The electric motor **10** can rotate at a rotation speed of 1000 rpm by applying, for example, an excitation current having an effective value of 10 A and a frequency of 100 Hz to each phase.

The stator **20** includes an adhesively-laminated core for a stator (hereinafter, a stator core) **21** and windings (not shown).

The stator core **21** includes an annular core back part **22** and a plurality of tooth parts **23**. Below, a direction of a central axis O of the stator core **21** (or the core back part **22**) is referred to as the axial direction, a radial direction (a direction orthogonal to the central axis O) of the stator core **21** (or the core back part **22**) is referred to as the radial direction, and a circumferential direction (a direction revolving around the central axis O) of the stator core **21** (core back part **22**) is referred to as the circumferential direction.

The core back part **22** is formed in an annular shape in a plan view of the stator **20** from the axial direction.

The plurality of tooth parts **23** extend inward in the radial direction (toward the central axis O of the core back part **22** in the radial direction) from an inner circumference of the core back part **22**. The plurality of tooth parts **23** are disposed at equal angular intervals in the circumferential direction. In the present embodiment, 18 tooth parts **23** are provided at every 20 degrees with respect to a central angle centered on the central axis O. The plurality of tooth parts **23** are formed to have the same shape and the same size as each other. Therefore, the plurality of tooth parts **23** have the same thickness dimension as each other.

The windings are wound around the tooth parts **23**. The windings may be concentrated windings or distributed windings.

The rotor **30** is disposed inside the stator **20** (stator core **21**) in the radial direction. The rotor **30** includes a rotor core **31** and a plurality of permanent magnets **32**.

The rotor core **31** is formed in an annular shape (an annular ring shape) disposed coaxially with the stator **20**. The rotation shaft **60** is disposed inside the rotor core **31**. The rotation shaft **60** is fixed to the rotor core **31**.

The plurality of permanent magnets **32** are fixed to the rotor core **31**. In the present embodiment, a set of two permanent magnets **32** form one magnetic pole. A plurality of sets of permanent magnets **32** are arranged at equal intervals in the circumferential direction. In the present embodiment, 12 sets (24 in total) of permanent magnets **32** are provided at every 30 degrees of the central angle centered on the central axis O.

In the present embodiment, an interior permanent magnet motor is adopted as a permanent magnetic electric motor. A plurality of through-holes **33** that penetrate the rotor core **31** in the axial direction are formed in the rotor core **31**. The plurality of through-holes **33** are provided to correspond to the plurality of permanent magnets **32**. Each permanent magnet **32** is fixed to the rotor core **31** in a state in which it is disposed in the corresponding through-hole **33**. Fixing of each permanent magnet **32** to the rotor core **31** can be realized, for example, by providing adhesion between an outer surface of the permanent magnet **32** and an inner surface of the through-hole **33** with an adhesive or the like. Also, as the permanent magnet electric motor, a surface permanent magnet motor may be adopted instead of an interior permanent magnet type.

The stator core **21** and the rotor core **31** are both laminated cores. For example, as shown in FIG. **2**, the stator core **21** is formed by laminating a plurality of electrical steel sheets **40** in the axial direction.

Further, a laminated thickness (the entire length along the central axis O) of each of the stator core **21** and the rotor core **31** is, for example, 50.0 mm. An outer diameter of the stator core **21** is, for example, 250.0 mm. An inner diameter of the stator core **21** is, for example, 165.0 mm. An outer diameter of the rotor core **31** is, for example, 163.0 mm. An inner diameter of the rotor core **31** is, for example, 30.0 mm. However, these values are examples, and the laminated thickness, the outer diameter, and the inner diameter of the stator core **21** and the laminated thickness, the outer diameter, and the inner diameter of the rotor core **31** are not limited to only these values. Here, the inner diameter of the stator core **21** is measured with tips of the tooth parts **23** of the stator core **21** as a reference. That is, the inner diameter of the stator core **21** is a diameter of a virtual circle inscribed in the tips of all the tooth parts **23**.

Each electrical steel sheet **40** forming the stator core **21** and the rotor core **31** is formed, for example, by punching an electrical steel sheet serving as a base material, etc. As the electrical steel sheet **40**, a known electrical steel sheet can be used. A chemical composition of the electrical steel sheet **40** includes 2.5% to 3.9% Si, as shown below in units of mass %. By setting the chemical composition in these ranges, a yield strength YP of each electrical steel sheet **40** can be set to 380 MPa or more and 540 MPa or less.

Si: 2.5% to 3.9%

Al: 0.001% to 3.0%

Mn: 0.05% to 5.0%

Remainder: Fe and impurities

In the present embodiment, a non-grain-oriented electrical steel sheet is used as the electrical steel sheet **40**. As the non-grain-oriented electrical steel sheet, for example, a non-grain-oriented electrical steel strip of JIS C 2552:2014 can be adopted. However, as the electrical steel sheet **40**, a grain-oriented electrical steel sheet may be used instead of a non-grain-oriented electrical steel sheet. As the grain-oriented electrical steel sheet in this case, a grain-oriented electrical steel strip of JIS C 2553:2012 can be adopted.

Phosphate-based insulation coating are provided on both surfaces of the electrical steel sheet **40** in order to improve workability of the stator core **21** (hereinafter, may be simply referred to as a "laminated core") and an iron loss of the laminated core. As a substance constituting the insulating coating, for example, (1) an inorganic compound, (2) an organic resin, (3) a mixture of an inorganic compound and an organic resin, and the like can be adopted. As the inorganic compound, for example, (1) a complex of dichromate and boric acid, (2) a complex of phosphate and silica, and the like can be exemplified. As the organic resin, an epoxy-based resin, an acrylic-based resin, an acrylic-styrene-based resin, a polyester-based resin, a silicone-based resin, a fluorine-based resin, and the like can be exemplified.

In order to ensure insulation performance between the electrical steel sheets **40** laminated with each other, a lower limit of an average thickness t1 of the insulation coating (an average thickness per one surface of the electrical steel sheet **40**) is preferably 0.3 μm, more preferably to 0.7 μm.

On the other hand, the insulation effect becomes saturated when the insulation coating becomes thicker. Further, as the insulation coating becomes thicker, a space factor of the electrical steel sheet **40** in the laminated core decreases, and the performance of the laminated core deteriorates. Therefore, the insulation coating may be as thin as possible within a range in which the insulation performance can be ensured. An upper limit of the average thickness of the insulation coating (a thickness per one surface of the electrical steel sheet **40**) is preferably 1.2 μm, more preferably 0.9 μm.

The average thickness t1 of the insulation coating is an average value of the entire laminated core. The thickness of the insulation coating is made to be almost the same over laminated positions thereof in the axial direction and a circumferential position around the central axis of the laminated core. For that reason, the average thickness t1 of the insulation coating can be set as a value measured at an upper end position of the laminated core.

As the thickness of the electrical steel sheet **40** becomes thinner, the proportion of the electrical steel sheet **40** in the laminated core decreases. Further, as the electrical steel sheet **40** becomes thinner, manufacturing costs of the electrical steel sheet **40** increase. For that reason, a lower limit of an average sheet thickness of the electrical steel sheet **40** is 0.15 mm, more preferably 0.18 mm in consideration of a decrease in the proportion of the electrical steel sheet **40** in the laminated core and the manufacturing costs.

On the other hand, if the electrical steel sheet **40** is too thick, the manufacturing costs become better, but an eddy current loss increases and a core loss deteriorates. For that reason, in consideration of the core loss and the manufacturing costs, an upper limit of the average sheet thickness of the electrical steel sheet **40** is 0.35 mm, more preferably 0.30 mm.

0.20 mm can be exemplified as one satisfying the above range of the average sheet thickness of the electrical steel sheet **40**. Also, the average thickness of the electrical steel sheet **40** includes the thickness of the insulation coating.

As shown in FIG. **3**, the plurality of electrical steel sheets **40** forming the stator core **21** are laminated, for example, via the adhesion parts **41** disposed in a shape of a plurality of points. Each of the adhesion parts **41** is formed of an adhesive that has been cured without being divided. For forming the adhesion part **41**, for example, a thermosetting type adhesive by polymer bonding or the like is used. As such an adhesive, a radical polymerization type adhesive or the like can also be used in addition to a thermosetting type adhesive, and from the viewpoint of productivity, a room temperature curing type adhesive is preferably used. The room temperature curing type adhesive cures at 20° C. to 30° C. As the room temperature curing type adhesive, an acrylic-based adhesive is preferable. A typical acrylic-based adhesive includes a second generation acrylic adhesive (SGA) and the like. Any of an anaerobic adhesive, an instant adhesive, and an elastomer-containing acrylic-based adhesive can be used within the range in which the effects of the present invention are not impaired. Also, the adhesive mentioned herein is an adhesive in a state before curing and becomes the adhesion part **41** after the adhesive is cured.

An average tensile modulus of elasticity E of the adhesion part **41** at room temperature (20° C. to 30° C.) is in the range of 1500 MPa to 4500 MPa. If the average tensile modulus of elasticity E of the adhesion part **41** is less than 1500 MPa, there will be a problem that rigidity of the laminated core is lowered. For that reason, a lower limit of the average tensile modulus of elasticity E of the adhesion part **41** is 1500 MPa, more preferably 1800 MPa. On the contrary, if the average tensile modulus of elasticity E of the adhesion part **41** exceeds 4500 MPa, there will be a problem that the insulation coating formed on the surface of the electrical steel sheet **40** is peeled off. For that reason, an upper limit of the average tensile modulus of elasticity E of the adhesion part **41** is 4500 MPa, more preferably 3650 MPa.

Also, the average tensile modulus of elasticity E is measured using a resonance method. Specifically, the tensile modulus of elasticity is measured in accordance with JIS R 1602:1995.

More specifically, first, a sample for measurement (not shown) is manufactured. This sample is obtained by providing adhesion between two electrical steel sheets **40** using an adhesive, which is a measurement target, and curing them to form the adhesion part **41**. In a case in which the adhesive is a thermosetting type, the curing is performed by heating and pressurizing it under heating and pressurizing conditions in actual work. On the other hand, in a case in which the adhesive is a room temperature curing type, the curing is performed by pressurizing it at room temperature.

In addition, the tensile modulus of elasticity of this sample is measured using the resonance method. As described above, the method for measuring the tensile modulus of elasticity using the resonance method is performed in accordance with JIS R 1602:1995. Then, the tensile modulus of elasticity of the adhesion part **41** alone can be obtained by removing an amount of influence of the electrical steel sheet **40** itself from the tensile modulus of elasticity (measured value) of the sample by calculation.

Since the tensile modulus of elasticity obtained from the sample in this way is equal to an average value of the entire laminated core, this value is regarded as the average tensile modulus of elasticity E. The composition is set such that the average tensile modulus of elasticity E hardly changes at laminated positions in the axial direction or at circumferential positions around the central axis of the laminated core. For that reason, the average tensile modulus of elasticity E can be set to a value obtained by measuring the adhesion part **41** after curing at the upper end position of the laminated core.

As a method of providing adhesion between the plurality of electrical steel sheets **40**, a method of adhering with which an adhesive is applied in a point shape to lower surfaces (surfaces on one side) of the electrical steel sheets **40**, then they are overlapped, and then one or both of heating and press-stacking are performed can be adopted. Also, a means in the case of heating may be any means such as a means for heating the stator core **21** in a high temperature bath or an electric furnace, or a method of directly energizing and heating the stator core **21**. On the other hand, in a case in which a room temperature curing type adhesive is used, they are adhered only by press-stacking without heating.

FIG. **3** shows an example of a formation pattern of the adhesion parts **41**. Each adhesion part **41** is formed in a shape having a plurality of points forming a circular shape. More specifically, in the core back part **22**, they are formed in point shapes having an average diameter of 12 mm at equal angular intervals in the circumferential direction thereof. Further, at a tip position of each tooth part **23**, the adhesion part **41** is formed in a point shape having an average diameter of 8 mm. The average diameters shown here are examples and can be appropriately selected from the range of 2 mm to 20 mm. In addition, the formation pattern of FIG. **3** is an example, and the number and arrangements of the adhesion parts **41** can be appropriately changed as needed. Also, the shape of each adhesion part **41** is not limited to a circular shape and may be a rectangular shape or another polygonal shape if necessary.

The average thickness t2 of the adhesion part **41** is 1.0 μm or more and 3.0 μm or less. When the average thickness t2 of the adhesion part **41** is less than 1.0 μm, a sufficient adhesion force cannot be secured. For that reason, a lower limit of the average thickness t2 of the adhesion part **41** is 1.0 μm, more preferably 1.2 μm. On the contrary, when the average thickness t2 of the adhesion part **41** becomes thicker than 3.0 μm, there will be problems such as a great increase in a strain amount of the electrical steel sheet **40** due to shrinkage during thermosetting. For that reason, an upper limit of the average thickness t2 of the adhesion part **41** is 3.0 μm, more preferably 2.6 μm, and most preferably 1.8 μm.

The average thickness t2 of the adhesion part **41** is an average value of the entire laminated core. The average thickness t2 of the adhesion parts **41** hardly changes at laminated positions in the axial direction and the circumferential position around the central axis of the laminated core. For that reason, the average thickness **12** of the adhesion parts **41** can be set as an average value of the numerical values measured at 10 or more points in the circumferential direction at the upper end position of the laminated core.

In addition, the average thickness t2 (μm) of the adhesion part **41** and the average thickness t1 (μm) of the insulation coating satisfy the following Equation 1.

$$-4.3\times t1+3.6\leq t2\leq -4.3\times t1+6.9 \quad \text{(Equation 1)}$$

Further, the average tensile modulus of elasticity F. of the adhesion parts **41** is 1500 MPa to 4500 MPa, and the average tensile modulus of elasticity E (MPa) and the average thickness t1 (μm) of the insulation coating satisfy the following Equation 2.

$$-5000\times t1+4500\leq E\leq -5000\times t1+9000 \quad \text{(Equation 2)}$$

First of all, regarding the above Equation 1, when the average thickness t2 of the adhesion parts **41** is thinner than −4.3×t1+3.6, the bond with the insulation coating is poor and the adhesion strength cannot be secured, and the mechanical strength of the stator core **21** cannot be maintained. On the other hand, when the average thickness t2 of the adhesion parts **41** becomes thicker than −4.3×t1+6.9, close adhesion between the insulation coating and the electrical steel sheet **40** tends to decrease due to the stress exerted by the adhesion parts **41** on the insulation coating. From the above, the average thickness t2 of the adhesion parts **41** is within the range of Equation 1.

Next, regarding the above Equation 2, when the average tensile modulus of elasticity E of the adhesion parts **41** is lower than −5000×t1+4500, the bond between the adhesion parts **41** and the insulation coating becomes poor and the adhesion strength cannot be maintained, and the mechanical strength of the stator core **21** may not be maintained. On the other hand, when the average tensile modulus of elasticity E of the adhesion parts **41** is higher than −5000×t1+9000, the stress exerted by the adhesion parts **41** on the insulation coating may reduce the adhesion between the insulation coating and the electrical steel sheet **40**. From the above, the average tensile modulus of elasticity E of the adhesion parts **41** is preferably within the range of Equation 2.

In addition, the average thickness of the adhesion parts **41** can be adjusted by changing, for example, an amount of an adhesive applied. Also, for example, in the case of a thermosetting type adhesive, the average tensile modulus of elasticity E of the adhesion parts **41** can be adjusted by changing one or both of the heating and pressurizing conditions and a type of a curing agent applied at the time of adhesion.

Further, for the above-mentioned reason, it is more preferable that the average thickness t1 (μm) and the average thickness t2 (μm) further satisfy the following Equations 3 and 4.

$$0.7\leq t1\leq 0.9 \quad \text{(Equation 3)}$$

$$1.2\leq t2\leq 2.6 \quad \text{(Equation 4)}$$

Also, in the present embodiment, the plurality of electrical steel sheets forming the rotor core **31** are fixed to each other by fastening **42** (dowels) shown in FIG. **1**. However, the plurality of electrical steel sheets forming the rotor core **31** may also have a laminated structure fixed by adhesion parts similarly to the stator core **21**. Further, the laminated cores such as the stator core **21** and the rotor core **31** may be formed by so-called turn-stacking.

Examples

Using a manufacturing device **100** shown in FIG. **4**, the stator core **21** was manufactured while changing various manufacturing conditions.

First, the manufacturing device **100** will be described. In the manufacturing device **100**, while feeding electrical steel sheets P from a coil C (a hoop) in a direction of arrow F, punching is performed a plurality of times by molds disposed on each stage to gradually form shapes of the electrical steel sheets **40**. Then, an adhesive is applied to lower surfaces of the electrical steel sheets **40**, and the punched electrical steel sheets **40** are laminated and pressed while raising a temperature. As a result, the adhesive is cured to form the adhesion parts **41**, and thus the adhesion is completed.

As shown in FIG. **4**, the manufacturing device **100** includes a first-stage punching station **110** at a position closest to the coil C, a second-stage punching station **120** adjacently disposed on a downstream side in a conveyance direction of the electrical steel sheet P from the punching station **110**, and an adhesive-coating station **130** adjacently disposed on a further downstream side thereof from the punching station **120**.

The punching station **110** includes a fixed mold **111** disposed below the electrical steel sheet P and a movable mold **112** disposed above the electrical steel sheet P.

The punching station **120** includes a fixed mold **121** disposed below the electrical steel sheet P and a movable mold **122** disposed above the electrical steel sheet P.

The adhesive-coating station **130** includes an applicator **131** including a plurality of injectors disposed in accordance with an adhesive coating pattern.

The manufacturing device **100** further includes a stacking station **140** at a downstream position from the adhesive-coating station **130**. The stacking station **140** includes a heating device **141**, a fixed mold for outer shape **142**, a heat insulation member **143**, a movable mold for outer shape **144**, and a spring **145**.

The heating device **141**, the fixed mold for outer shape **142**, and the heat insulation member **143** are disposed below the electrical steel sheet P. On the other hand, the movable mold for outer shape **144** and the spring **145** are disposed above the electrical steel sheet P. Also, reference numeral **21** indicates the stator core.

In the manufacturing device **100** having the configuration described above, first, the electrical steel sheet P is sequentially sent out from the coil C in the direction of arrow F of FIG. **4**. Then, the electrical steel sheet P is, first, punched by the punching station **110**. Subsequently, the electrical steel sheet P is punched by the punching station **120**. By these punching processes, the shape of the electrical steel sheet **40** having the core back part **22** and the plurality of tooth parts **23** shown in FIG. **3** is obtained on the electrical steel sheet P. However, since it is not completely punched at this point, the process proceeds to the next step in the direction of arrow F. In the adhesive-coating station **130** in the next step, the adhesive supplied from each of the injectors of the applicator **131** is applied in a point shape.

Then, finally, the electrical steel sheet P is sent out to the stacking station **140**, punched out by the movable mold for outer shape **144**, and laminated with high accuracy. At the time of this stacking, the electrical steel sheet **40** receives a constant pressing force by the spring **145**.

By sequentially repeating the punching process, the adhesive-coating process, and the stacking process as described above, a predetermined number of electrical steel sheets **40** can be laminated. Further, the laminated core formed by stacking the electrical steel sheets **40** in this way is heated to, for example, a temperature of 200° C. by the heating device **141**. This heating cures the adhesives to form the adhesion parts **41**.

The stator core **21** is completed through each of the above steps.

Using the manufacturing device **100** described above, the stator cores **21** shown in No. 1 to No. 29 in Tables 1A and 1B were manufactured. The chemical components of the electrical steel sheet **40** used in manufacturing each stator core **21** were unified as follows. In addition, each component value indicates mass %.

Si: 3.1%

Al: 0.7%

Mn: 0.3%

Remainder: Fe and impurities

TABLE 1A

No.	Electrical steel sheet Average sheet thickness (mm)	Insulation coating Average thickness t1 (μm)	Adhesion part: Adhesive used	Adhesion part: Average thickness t2 (μm)	Adhesion part: Average tensile modulus of elasticity (MPa)	Adhesion part: Whether or not to satisfy Equation 1(*a)	Adhesion part: Whether or not to satisfy Equation 2(*b)
1	0.20	0.3	Elastomer-based	2.4	3600	Satisfied	Satisfied
2	0.20	0.3	Elastomer-based	2.8	4200	Satisfied	Satisfied
3	0.20	0.5	Elastomer-based	1.5	2300	Satisfied	Satisfied
4	0.20	0.5	Elastomer-based	2.1	3200	Satisfied	Satisfied
5	0.20	0.5	Elastomer-based	2.7	4100	Satisfied	Satisfied
6	0.20	0.7	Elastomer-based	1.6	2400	Satisfied	Satisfied
7	0.20	0.7	Elastomer-based	2.3	3500	Satisfied	Satisfied
8	0.20	0.8	Elastomer-based	1.4	2100	Satisfied	Satisfied
9	0.20	0.8	Elastomer-based	2.7	4100	Satisfied	Satisfied
10	0.20	0.9	Elastomer-based	1.8	2700	Satisfied	Satisfied
11	0.20	0.9	Elastomer-based	2.3	3500	Satisfied	Satisfied
12	0.20	1.0	Elastomer-based	1.6	2400	Satisfied	Satisfied
13	0.20	1.0	Elastomer-based	2.2	3300	Satisfied	Satisfied
14	0.20	1.2	Elastomer-based	1.1	2000	Satisfied	Satisfied
15	0.20	1.2	Elastomer-based	1.3	2000	Satisfied	Satisfied
16	0.20	0.1	Elastomer-based	1.2	1800	Unsatisfied	Unsatisfied
17	0.20	0.1	Elastomer-based	2.1	3200	Unsatisfied	Unsatisfied
18	0.20	0.3	Elastomer-based	1.3	2000	Unsatisfied	Unsatisfied
19	0.20	0.3	Elastomer-based	3.4	5100	Satisfied	Satisfied
20	0.20	0.4	Elastomer-based	1.2	1800	Unsatisfied	Unsatisfied
21	0.20	0.6	Elastomer-based	3.6	5400	Satisfied	Satisfied
22	0.20	0.8	Elastomer-based	0.5	800	Satisfied	Satisfied
23	0.20	0.8	Elastomer-based	3.2	4800	Satisfied	Satisfied
24	0.20	1.1	Elastomer-based	0.7	1100	Satisfied	Satisfied
25	0.20	1.1	Elastomer-based	2.6	3900	Unsatisfied	Unsatisfied
26	0.20	1.5	Elastomer-based	0.8	1200	Unsatisfied	Satisfied
27	0.20	1.4	Elastomer-based	2.8	4200	Unsatisfied	Unsatisfied
28	0.20	0.8	Anaerobic adhesive	2.8	4200	Satisfied	Satisfied
29	0.20	1.1	Elastomer-based	2.0	4200	Satisfied	Unsatisfied

(*a)$-4.3 \times t1 + 3.6 \leq t2 \leq -4.3 \times t1 + 6.9$ . . . (Equation 1)

(*b)$-5000 \times t1 + 4500 \leq E \leq -5000 \times t1 + 9000$ . . . (Equation 2)

TABLE 1B

	Mechanical strength		Presence or absence of peeling of insulation	Magnetic properties		Example/ Comparative
No.	(MPa)	Decision	coating	W 15/50	Decision	example
1	6	Good	Absence	2.53	Good	Example
2	8	Good	Absence	2.56	Good	Example
3	7	Good	Absence	2.50	Excellent	Example
4	6	Good	Absence	2.56	Good	Example
5	10	Excellent	Absence	2.58	Good	Example
6	10	Excellent	Absence	2.49	Excellent	Example
7	5	Good	Absence	2.59	Good	Example
8	9	Excellent	Absence	2.50	Excellent	Example
9	5	Good	Absence	2.53	Good	Example
10	9	Excellent	Absence	2.51	Excellent	Example
11	7	Good	Absence	2.57	Good	Example
12	6	Good	Absence	2.50	Excellent	Example
13	6	Good	Absence	2.58	Good	Example
14	7	Good	Absence	2.59	Excellent	Example
15	5	Good	Absence	2.51	Excellent	Example
16	6	Good	Absence	2.74	Poor	Comparative example
17	9	Excellent	Absence	2.79	Poor	Comparative example
18	1	Poor	Absence	2.63	Good	Comparative example
19	10	Excellent	Presence	2.87	Poor	Comparative example
20	2	Poor	Absence	2.58	Good	Comparative example
21	10	Excellent	Presence	2.74	Poor	Comparative example
22	1	Poor	Absence	2.58	Good	Comparative example
23	9	Excellent	Presence	2.81	Poor	Comparative example
24	1	Poor	Absence	2.57	Good	Comparative example
25	2	Poor	Absence	2.56	Good	Comparative example
26	7	Good	Presence	2.57	Good	Comparative example
27	8	Good	Presence	2.53	Good	Comparative example
28	6	Good	Presence	2.83	Poor	Comparative example
29	5	Good	Absence	2.54	Good	Example

Specifically, a plurality of hoops (coils C) having the above chemical components were manufactured. A sheet thickness of a base steel of each hoop was unified to 0.20 mm. Then, an insulation coating treatment agent containing a metal phosphate and an acrylic resin emulsion was applied to each of these hoops and baked at 300° C. to form insulation coatings on both front and back surfaces thereof. At that time, thicknesses of the insulation coatings were changed for each hoop. Specifically, as shown in Table 1A, each insulation coating was formed such that the average thickness t1 (μm) on one surface becomes 0.1 μm, 0.3 μm, 0.4 μm, 0.5 μm, 0.6 μm, 0.7 μm, 0.8 μm, 0.9 μm, 1.0 μm, 1.1 μm, 1.2 μm, 1.4 μm, and 1.5 μm.

Then, the hoop set in the manufacturing device **100** was changed, or the type of adhesive applied to the electrical steel sheet **40**, the type of curing agent added to the adhesive, the type of curing accelerator, and a coating film thickness were changed, whereby as shown in Table 1 A, a plurality of laminated cores (stator cores **21**) having different combinations of the average thickness t1 of the insulation coating, the type of adhesive, the average thickness t2 of the adhesion part **41**, and the average tensile modulus of elasticity E were manufactured.

Specifically, first, one of the hoops was set in the manufacturing device **100**. Then, while feeding out the electrical steel sheet P from this hoop in the direction of arrow F in FIG. **4**, a single-plate core (the electrical steel sheet **40**), which has a ring shape with an outer diameter of 300 mm and an inner diameter of 240 mm and is provided with **18** rectangular tooth parts **23** having a length of 30 mm and a width of 15 mm on an inner diameter side thereof was punched out.

Subsequently, while the punched single-plate core was sequentially fed, it was applied with the adhesive in a point shape at each position shown in FIG. **3**, then laminated, heated while pressed at a predetermined pressure, and cured. The same work was repeated for 130 single-plate cores and one laminated core (the stator core **21**) was manufactured.

By performing the same process for each hoop while changing each combination condition, 29 types of laminated cores shown in No. 1 to No. 29 in Tables 1A and 1B were manufactured.

In addition, as the adhesive, a second generation acrylic-based adhesive was used as an elastomer-based adhesive in No. 1 to No. 27 and No. 29. On the other hand, in No. 28, a general-purpose anaerobic adhesive was used as an anaerobic adhesive.

Further, the average thickness t2 of the adhesion parts **41** was adjusted by changing the coating amount for each laminated core. Also, the average tensile modulus of elasticity E of the adhesion parts **41** was adjusted for each laminated core by changing one or both of the heating and pressurizing conditions and the type of curing agent applied at the time of adhesion at the stacking station **140**.

Each laminated core manufactured using the method described above was cut in a cross-section including their axes. Then, the average thickness t1 (μm) of the insulation coatings was determined. Further, in the adhesion parts **41**, the average thickness t2 (μm) and the average tensile modulus of elasticity E after curing were determined. The average tensile modulus of elasticity E was determined using the method described above. An outer diameter of each point-shaped adhesive after curing was 5 mm on average.

Then, the average thickness t1 (μm), the average thickness t2 (μm), and the average tensile modulus of elasticity E (MPa) were substituted into the above-mentioned Equations 1 and 2 and were determined whether or not Equations 1 and 2 were satisfied. The results are shown in Table 1A.

Further, rigidity (mechanical strength) of the laminated core was also evaluated. The mechanical strength was evaluated with a magnitude of a load when a cutting edge with a width of 20 mm, a tip angle of 10°, and 0.15 mm R was gradually pressed against a laminated part (between a pair of electrical steel sheets **40** adjacent to each other) of the laminated core while increasing the load to generate cracks. A higher load is more preferable, and the one having 4 MPa or more was judged to be good or excellent. In the mechanical strength of the laminated core in Table 1B, "excellent" indicates that high mechanical strength is secured, "good" indicates that necessary and sufficient mechanical strength is secured, and "poor" indicates that the minimum required mechanical strength is not secured.

Further, presence or absence of peeling of the insulation coating was also evaluated. Regarding the presence or absence of peeling of the insulation coating in Table 1B, "absence" indicates a state in which there is no peeling, and "presence" indicates a state in which peeling occurs in places.

Furthermore, the magnetic properties of the laminated core were also evaluated. When the magnetic properties were evaluated, the number of laminated sheets was set to 20, winding was performed after covering the laminated core with insulating paper, and the core loss (W15/50 in Table 1B) was measured at a frequency of 50 Hz and a magnetic flux density of 1.5 Tesla. Here, the number of lamination of the electrical steel sheets **40** when the evaluation of the magnetic properties was performed was set to 20 because almost the same results as in the case of 130 can be obtained.

A lower core loss (W15/50 in Table 1B) is more preferable, and the one having 2.70 or less was decided to be good or excellent. In the magnetic properties of the laminated cores in Table 1B, "excellent" indicates that high magnetic properties can be secured, "good" indicates that necessary and sufficient magnetic properties are secured, and "poor" indicates that the minimum required magnetic properties are not secured.

Further, FIG. **5** shows a relationship between the average thickness t1 of the insulation coatings and the average thickness t2 of the adhesion parts **41** shown in Table 1A. Similarly, FIG. **6** shows a relationship between the average thickness t1 of the insulation coatings and the average tensile modulus of elasticity E of the adhesion parts **41** shown in Table 1A.

As shown in Tables 1A and 1B, in the comparative examples shown in Nos. 16 and 17, the average thickness t1 of the insulation coatings was thin and the magnetic properties deteriorated.

Also, in the comparative example shown in No. 18, unevenness of the insulation coatings could not be filled, and the mechanical strength decreased.

Also, in the comparative example shown in No. 19, the average thickness t2 of the adhesion parts **41** was thick, the proportion of the electrical steel sheets **40** in the laminated core decreased, and the magnetic properties deteriorated.

Also, in the comparative example shown in No. 20, the unevenness of the insulation coatings could not be filled, and the mechanical strength decreased.

Also, in the comparative example shown in No. 21, the average thickness t2 of the adhesion parts **41** was thick, the proportion of the electrical steel sheets **40** in the laminated core decreased, and the magnetic properties deteriorated.

Also, in the comparative example shown in No. 22, the average thickness t2 of the adhesion parts **41** was thin, the adhesion strength was lowered, and the mechanical strength was lowered.

Also, in the comparative example shown in No. 23, the average thickness t2 of the adhesion parts **41** was thick, the proportion of the electrical steel sheets **40** in the laminated core decreased, and the magnetic properties deteriorated.

Also, in the comparative example shown in No. 24, the average thickness t2 of the adhesion part **41** was thin, the adhesion strength was lowered, and the mechanical strength was lowered.

Also, in the comparative example shown in No. 25, since the average thickness t1 of the insulation coatings was relatively thick and the adhesion tended to decrease, the upper limit of the average thickness t2 of the adhesion parts **41** (the upper limit of the average tensile modulus of elasticity E) substantially decreased, and the mechanical strength decreased.

Also, in the comparative example shown in No. 26, the average thickness t1 of the insulation coatings was thick, the adhesion was lowered, and the coatings were peeled off.

Also, in the comparative example shown in No. 27, the average thickness t1 of the insulation coatings was thick, the adhesion was lowered, and the coatings were peeled off.

Further, although the comparative example shown in No. 28 was in the region shown in each of FIGS. **5** and **6**, the adhesive used for adhesion was an anaerobic adhesive and did not have a sea-island structure, and thus the cured adhesion parts **41** generated strain in the electrical steel sheets **40**, and due to the strain of the electrical steel sheets **40**, the magnetic properties deteriorated.

On the other hand, in Nos. 1 to 15 and 29, which are the examples, it was confirmed that the rigidity (mechanical strength) of the laminated core was high, the insulation coatings were not peeled off, and the magnetic properties (W15/50) had desired performance.

Among these examples, in particular, in Nos. 3, 6, 8, 10, 12, 14, and 15, since the average thickness t2 of the adhesion parts **41** was 1.8 μm or less, even higher magnetic properties were be obtained than in other examples.

Further, among these, in Nos. 6, 8 and 10, the average thickness t1 of the insulation coatings also satisfies the range of 0.7 μm to 0.9 μm. For that reason, optimization has been performed with respect to securing of insulation performance is deterioration of performance as a laminated core, which is the most preferable among all the examples.

Also, in the present examples, a thermosetting type adhesive was applied, but there is no difference in the basic tendency even with a room temperature curing type adhesive.

The embodiment and the examples of the present invention have been described above. However, the technical scope of the present invention is not limited to the above-described embodiment and the examples, and various changes can be added thereto without departing from the spirit of the present invention.

For example, the shape of the stator core **21** is not limited to the form shown in the above embodiment. Specifically, dimensions of the outer diameter and the inner diameter of the stator core **21**, the laminated thickness, the number of slots, a dimensional ratio of the tooth part **23** between in the circumferential direction and in the radial direction, a dimensional ratio in the radial direction between the tooth part **23** and the core back part **22**, and the like can be arbitrarily designed in accordance with desired properties of the electric motor.

In the rotor **30** of the above embodiment, the set of two permanent magnets **32** form one magnetic pole, but the present invention is not limited thereto. For example, one permanent magnet **32** may form one magnetic pole, or three or more permanent magnets **32** may form one magnetic pole.

In the above-described embodiment, the permanent magnetic electric motor has been described as an example of the electric motor **10**, but as illustrated below, the structure of the electric motor **10** is not limited thereto, and various known structures not illustrated below can also be adopted.

In the above-described embodiment, the permanent magnetic electric motor has been described as an example of the electric motor **10**, but the present invention is not limited thereto. For example, the electric motor **10** may be a reluctance motor or an electromagnet field motor (a wound-field motor).

In the above-described embodiment, the synchronous motor has been described as an example of the AC motor, but the present invention is not limited thereto. For example, the electric motor **10** may be an induction motor.

In the above-described embodiment, the AC motor has been described as an example of the electric motor **10**, but the present invention is not limited thereto. For example, the electric motor **10** may be a DC motor.

In the above-described embodiment, the motor has been described as an example of the electric motor **10**, but the present invention is not limited thereto. For example, the electric motor **10** may be a generator.

In addition, within the range not departing from the spirit of the present invention, it is possible to replace the components in the embodiment with well-known components as appropriate, and the above-mentioned modified examples may be combined with each other as appropriate.

INDUSTRIAL APPLICABILITY

According to the present invention, an adhesively-laminated core for a stator that can both prevent peeling of an insulation coating and inhibit deterioration of magnetic properties due to a stress applied to an electrical steel sheet by an adhesion part, and an electric motor including the adhesively-laminated core for the stator can be provided. Therefore, it provides great industrial applicability.

BRIEF DESCRIPTION OF THE REFERENCE SYMBOLS

10 Electric motor
21 Laminated core (adhesively-laminated core for stator)
40 Electrical steel sheet
41 Adhesion part

What is claimed is:

1. An adhesively-laminated core for a stator comprising:

a plurality of electrical steel sheets which have phosphate-based insulation coatings on surfaces thereof and are overlapped coaxially with each other; and

adhesion parts provided between the respective electrical steel sheets,

wherein an average thickness of the insulation coatings is 0.3 μm to 1.2 μm,

an average thickness of the adhesion parts is 1.0 μm to 3.0 μm, and

in a case where the average thickness of the insulation coating is defined as t1 in a unit of μm, and the average thickness of the adhesion parts is defined as t2 in a unit of μm, the following Equation 1 is satisfied,

$$-4.3\times t1+3.6\leq t2\leq -4.3\times t1+6.9 \quad \text{(Equation 1)}$$

wherein an average tensile modulus of elasticity E of the adhesion parts is 1500 MPa to 4500 MPa, and

the average tensile modulus of elasticity E (MPa) and the average thickness t1 (μm) of the insulation coating satisfy the following Equation 2,

$$-5000\times t1+4500\leq E\leq -5000\times t1+9000 \quad \text{(Equation 2).}$$

2. The adhesively-laminated core for the stator according to claim **1**,

wherein the average thickness t1 is 0.7 μm to 0.9 μm, and the average thickness t2 is 1.2 μm to 2.6 μm.

3. The adhesively-laminated core for the stator according to claim **1**,

wherein the average tensile modulus of elasticity E is 1800 MPa to 3650 MPa, and

the average thickness t1 is 0.7 μm to 0.9 μm.

4. The adhesively-laminated core for the stator according to claim **1**, wherein the adhesion parts are room temperature curing type acrylic-based adhesives each containing SGA made of an elastomer-containing acrylic-based adhesive.

5. The adhesively-laminated core for the stator according to claim **1**, wherein an average sheet thickness of the electrical steel sheets is 0.15 mm to 0.35 mm.

6. An electric motor comprising the adhesively-laminated core for the stator according to-claim **1**.

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